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Peaceful Nuclear Explosions (NOVIKOV S.A., 1999), PHYSICS

More than half a century has passed since the first nuclear explosion... Currently, there are very different points of view on the role and prospects of explosive nuclear energy in the modern world. The article examines the main issues of the peaceful use of nuclear explosions, which have received much attention in the leading nuclear powers over the past period: nuclear explosions for industry, scientific research and energy.

PEACEFUL NUCLEAR EXPLOSIONS

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The enormous destructive power of nuclear charges has long caused a negative attitude towards them among the absolute majority of the Earth's population. Fear of the possible use of nuclear charges in military conflicts, typical of the modern, not yet sufficiently stable world, inclines public opinion in favor of a complete ban on nuclear weapons and the destruction of all stocks of uranium-235 and plutonium. The media have long been discussing the role and prospects of nuclear weapons in the modern world.

The popular science magazine "Atom", created in 1994 on the initiative of nuclear scientists from the Russian Federal Nuclear Center (RFNC) Arzamas-16 (now Sarov), quite often publishes articles on this topic by famous Russian scientists, direct developers of the most powerful weapons of the 20th century. The photograph of the cover of the first issue of the magazine "Atom" is shown in Fig. 1. In an appeal to readers on the first page of this issue, the editors, in particular, wrote:

"We want the nuclear mushroom on the cover of the first issue of our popular science magazine to also symbolize the fact that a nuclear explosion is a unique tool for conducting fundamental research in modern physics. The figures of Cervantes' heroes should symbolize the heroism and romance of the creators of our country's atomic weapons."

Can nuclear explosions be useful for humanity? This problem is given much attention on the pages of the magazine.

In this article, the author, being the editor-in-chief of the journal "Atom", a witness and participant in a number of such works, has attempted to briefly summarize these publications. We will not touch upon political issues such as: is nuclear weapons a stabilizing factor in maintaining peace, etc.? Let us consider three directions in the peaceful use of nuclear explosions: for industry; for scientific research; for energy.

The work uses materials from articles published in the journal "Atom" by famous scientists from Russian nuclear centers (Sarov and Snezhinsk) B.V. Litvinov, V.N. Mokhov, S.N. Kholin, A.K. Chernyshev, E.K.

Bonyushkin, N.P. Voloshin, R.F. Trunin, E.G. Malykhin and others, as well as materials published in 1997 [1].

## PEACEFUL NUCLEAR EXPLOSIONS

## FOR INDUSTRY

The enormous energy released during nuclear explosions has led to the idea of using it for peaceful purposes since the very beginning of work on nuclear weapons. Each kilogram of thermonuclear fuel is capable of releasing energy in a thermonuclear device equivalent to the explosion of 30 thousand tons of explosive. A nuclear explosion (NE) of such power costs about a million dollars. With a further increase in the power of a nuclear device by tens and hundreds of times, its cost increases insignificantly. Today, a thermonuclear explosion is the most powerful and at the same time the cheapest source of energy on Earth. The existing objections to the technical use of NE are quite serious and justified. First of all, they are related to the danger of radioactive contamination of the environment and the large energy release during NE. After all, errors in the use of nuclear charges (NC), even in the absence of radioactivity, can lead to great disasters precisely because of the large scale of work carried out by NE.

The requirements for peaceful nuclear charges differ significantly from the requirements for warheads. On the one hand, these requirements are softer, since there are no strict conditions for the mass of the nuclear charge, its shape (placement in carriers), or service life. On the other hand, some requirements are higher, for example: the permissible amount of fission fragments formed during the explosion, the amount of unburned plutonium and tritium, the chemical composition of the structural materials, etc. In military thermonuclear charges, approximately half of the energy is released in the fission reactions of uranium and plutonium nuclei with the formation of a corresponding amount of radioactive fission fragments. This is the main obstacle to the use of such charges in industry. If all the energy of the explosion were obtained in fusion reactions, the radioactivity would be mainly determined by unburned tritium and the activation of various materials of the charge and the environment by neutrons. Such induced radioactivity could be hundreds of times less than in the explosion of a warhead. No one knows how to make a nuclear charge that would completely lack fission fragments during an explosion. Clean peaceful thermonuclear charges are charges in which the main share of energy is released in thermonuclear reactions (> 90%). The degree of purity of such a charge is the ratio of the energy obtained in fusion reactions to the total energy of the explosion, expressed as a percentage. If, for example, the total energy is 100 kt of TNT equivalent (i.e.), the amount of fissile material burned is 100 g, which corresponds to an energy release of approximately 1.6 kt i.e., then the purity of the charge

The enormous work carried out in Russian nuclear centers (VNIIEF, Sarov and VNIITF, Snezhinsk) by large teams of theorists, mathematicians, designers, and experimenters made it possible to create clean industrial charges, begin developing projects for their peaceful use, and carry out some experiments.

An equally important problem for the industrial use of nuclear weapons is the study of their impact on the environment surrounding the charge. Uncertainties in the knowledge of the properties of substances surrounding the nuclear charge, errors in their mathematical description can lead to significant errors in predicting the action of the nuclear charge. The release of enormous energy from a nuclear charge occurs extremely quickly and with such intensity that in less than a millionth of a second (10-6 s) the charge itself and the material of the adjacent structures are transformed into hot (with a temperature of up to tens of millions of degrees) dense plasma. During an underground explosion, this inflating ball with gigantic pressure collapses onto the rock surrounding the explosion chamber, turning it into a dense, but less hot gas. The compression of the substance reaches 4-5 times. A powerful spherically diverging shock wave spreads from the center of the explosion at a speed of tens of kilometers per second. The amplitude of the shock wave in the rock is so great that at a distance of several hundred meters from the center of the explosion, intense crushing of the rock occurs. When reaching the earth's surface, the shock wave breaks off entire slabs of rock up to tens to hundreds of meters thick and up to several kilometers wide. Thousands of kilometers from the explosion site, even on the opposite side of the globe, the echo of the explosion can be recorded as a seismic vibration of the earth's crust. The pressure near a nuclear explosion (we are talking about a nuclear explosion with a capacity of several tens of kilotons of TNT equivalent) reaches a billion atmospheres, which can be compared with the pressure inside stars. The behavior of substances at such pressures is described numerically by quantum-mechanical laws. For a theoretical description of the properties of substances at lower pressures (as the shock wave moves away from the center of the explosion), it is necessary to use experimental data. Research by scientists at Russian and American nuclear laboratories has obtained reliable data on the equations of state of many substances in a wide range of pressures.

Statements by official representatives of the USSR about the need to study nuclear weapons for peaceful purposes were made in 1949. In the USA, this was noticed in 1956. During 1957-1958, an extensive program for conducting nuclear weapons for scientific and industrial purposes, "Project Plowshare", was formed there. The number of grandiose projects using nuclear weapons included the construction of another Panama Canal, the construction of a huge harbor on the coast of Alaska, etc. In the interests of the "Plow" program, a series of nuclear explosions in different soils were conducted at the Nevada test site, and extensive research was carried out on the numerical modeling of buried nuclear weapons.

In the USSR, the first pilot industrial nuclear explosion for release was carried out at a depth of 178 m on January 15, 1965 near the Chagan River, near the border of the Semipalatinsk nuclear test site. The power of the explosion was equivalent to 140 kt. A giant funnel up to 100 m deep and ~410 m in diameter was formed. The purpose of the explosion was to build a reservoir in an arid region. This reservoir still exists. Fish have appeared in it, and the water from the reservoir is completely suitable for drinking.

With the help of nuclear explosions, oil and gas extraction was intensified in our country, huge spherical tanks for storing oil and gas products were built in the thickness of salt deposits, and geophysical seismic exploration was successfully carried out. Explosions to crush apatite ore on the Kola Peninsula were successful, and methods for removing radioactivity from crushed ore were implemented. The extracted ore was absolutely clean. The only low-power nuclear explosion in a coal mine 5 km from the city of Yenakiyevo eliminated gas emissions for many years.

In a nuclear weapon of this type, the following requirements come to the forefront: small diameter, allowing the charge to be lowered into deep wells, increased heat resistance of the charge, allowing it to operate at high temperatures at great depths, and the ability to withstand high pressures. Such charges were created in the nuclear centers of Russia. Let us dwell in a little more detail on the elimination of a powerful gas fountain in Uzbekistan at the Urta-Bulak field using a nuclear weapon. On December 1, 1963, an open gas fountain 70 m high with a volume of emitted gas of 18 million m3 per day arose in one of the exploratory wells. Due to the content of methane and hydrogen sulfide, this fountain posed a great danger to the environment and was ignited to prevent poisoning of people and animals. The fountain burned for three years. So much gas was burned annually that it would be enough to supply such an industrial center as Yekaterinburg. Attempts to eliminate the fountain by all the usual known methods were unsuccessful. Nuclear physicists were given the task of creating a nuclear reactor core to shut off the well in the shortest possible time, which could withstand a temperature of 73°C at a depth of 1.5 km. The scheme for stopping a burning gas fountain is shown in Fig. 2. The explosion was preceded by dramatic situations associated with lowering the nuclear reactor core into the well. The experiment was successful: a few seconds after the explosion, the flame went out forever.

Another example of the application of nuclear weapons has not yet been realized, but its enormous significance for all mankind has already been noted in the final documents of several international symposiums. We are talking about a potential danger threatening the Earth from space - the possibility of a collision of our planet with two types of objects in the Solar System: asteroids and comets. (If they enter the Earth's atmosphere, they are called meteorites.) About 100 asteroids larger than a kilometer are known. It is believed that their total number is an order of magnitude greater. Such a collision does not mean the end of the world. History knows many examples of asteroids falling on Earth. When colliding with an asteroid 20 km in diameter, a crater up to 200 km in diameter can be expected to form. The fall of such an asteroid 65 million years ago, according to the hypothesis of L. Alvarez (USA, 1980), changed the climate on Earth so much that it caused the extinction of the dinosaurs. In any case, the scale of the possible catastrophe is such that one should hardly reassure oneself with its low probability. In 1966, a prediction was made about the possibility of a collision with the Earth of the asteroid Icarus, 0.5 km in diameter. At the same time, a proposal was made to shoot it down with missiles with nuclear warheads.

Two methods of influencing space objects that threaten our planet are proposed. First, using a nuclear weapon, it is possible to change the trajectory of an asteroid. Second, by accurately hitting it, it can be crushed. (In this case, the threat of asteroid fragments falling to Earth, however, remains, but the level of impact is significantly reduced.) Since the distances to the interception point are enormous due to safety requirements, this imposes strict requirements for the timely detection of dangerous celestial bodies and the calculation of their trajectories. Even the so-called operational interception, when the danger is noticed late, should, according to missile scientists, occur 30-90 days before the expected collision. Naturally, to protect against such global catastrophes, it is necessary to unite all the scientists of the world.

Finally, another unrealized but practically developed project for the use of nuclear weapons was the nuclear explosive craft, the idea of which was put forward by Andrei Dmitrievich Sakharov in 1962 at the Federal Nuclear Center (Sarov). A.D. Sakharov's idea was to use nuclear weapons to launch a huge payload into space. The propulsion system was supposed to use the energy of successive nuclear explosions. A payload of 1000 tons or more was supposed to ensure the crew's long-term stay in space. The task of developing such an explosive craft turned out to be very difficult. Nevertheless, as a result of the design work, a conclusion was nevertheless made about the possibility of creating a propulsion system using nuclear weapons energy. The basic diagram of the explosive craft as originally proposed by A.D. Sakharov is shown in Fig. 3, a. Fig. 3, b reproduces the design diagram of one of the PK-5000 explosive craft variants (5000 is the total weight in tons). By the way, at the suggestion of A.D. When Sakharov was developing the design, the issue of placing chlorella plantations in his living compartment was considered, with the expectation of feeding 10-20 people.

We have given here only a few of the known examples of the use of nuclear weapons in industry. Among the problems solved with the help of nuclear weapons and having (like asteroid safety) universal significance, we can include, in particular, such as the elimination of highly active waste from nuclear energy and nuclear power plants, as well as the elimination of chemical weapons and especially dangerous chemically toxic materials and waste.

Within the framework of these tasks, nuclear weapons will be aimed at solving fundamental environmental problems and will be used to eliminate various types of weapons of mass destruction. The development of these types of peaceful nuclear technologies has been carried out at the Russian Federal Nuclear Center since 1989.

NUCLEAR EXPLOSION - A UNIQUE TOOL FOR CONDUCTING FUNDAMENTAL RESEARCH

IN PHYSICS

Radiation of nuclear waves for pumping laser media

A nuclear explosion is, first of all, a gigantic pulsed source of penetrating nuclear radiation, in which even with the most modest energy release (no more than 1 kt e.) in a very short time (10- 8-10- 7 s) 1023-1024 neutrons and gamma quanta are born. In such radiation fields, research can be conducted that is inaccessible to any of the modern laboratory installations, for example: nuclear reactions can be studied (including on microquantities of rare artificial isotopes), experiments can be conducted on the formation of distant transuranium elements. The enormous concentration of energy in a nuclear explosion allows for unique research in the field of high-pressure and high-density physics, also inaccessible in laboratory conditions.

One of the interesting areas is the study of laser thermonuclear fusion. For such studies, some countries have built and operate unique installations with laser energy of up to several tens of kilojoules: Iskra-5 (VNIIEF, Russia, Sarov), NOVA (LLNL, USA, Livermore), Gekko XII (Japan), and new, more advanced installations are being developed. The main problem is obtaining laser energy in the range of hundreds of kilojoules and even megajoules, and, finally, for igniting thermonuclear targets on which the radiation of several lasers is focused. When studying this problem, a nuclear explosion may prove to be an indispensable source of pulsed gamma radiation for pumping powerful gas lasers. This refers to a small nuclear explosion - no more than 1 kt, implemented in compliance with existing environmental standards. High gamma radiation densities ((1-5) " 1016 gamma/cm2 at a distance of 5-10 m from the source) allow such an explosion to be used as a source for pumping large volumes of laser media with a high specific power (10-100 MW/cm3). The comparatively small dimensions of the radiation source provide high spatial and temporal symmetry. This is an extremely important factor in the design of multichannel laser systems. It is easy to see that under such favorable conditions, even with very modest efficiency values (3-5% of the input energy), it is possible to create laser systems for studying thermodynamic synthesis with an energy in a pulse of 105-106 joules.

Study of compressibility of substances

at high pressures in shock waves

The study of the behavior of substances under high pressures during shock-wave compression is of great scientific and practical importance. Theoretical processing of the results of such studies provides information on the equation of state of substances under high pressures, which is very important for solving some problems in geophysics, astrophysics and other areas of science. When exposed to strong shock waves, complex physical

processes occur in substances: compression of the crystal lattice, accompanied by thermal excitation of nuclei and electrons, melting, transition of electrons to internal orbits of the atom, etc. A further increase in pressure causes ionization of atoms, excitation and socialization of electrons. A certain average state is established, in which the individual properties of crystals are weakly manifested. In these studies, experimental methods of studying condensed matter in a compressed state acquire a special role. Extensive research in this direction was started in Russia and abroad in the 1940s in relation to the creation of nuclear weapons. Special explosive devices were developed that made it possible to achieve pressures of up to 2000 GPa in laboratory experiments. Data on the behavior of substances at high pressures created with the help of these devices are obtained by processing the results of measurements of shock wave parameters in samples of the materials being studied. A further significant increase in pressures at the shock wave front (up to 10,000 GPa) was achieved in underground nuclear tests.

Experimental assemblies with the studied samples and sensors recording the parameters of shock waves are located in the soil or rocks in special niches at different distances from the epicenter of the explosion. In this way, under the conditions of one explosion, it is possible to measure compressibility covering a huge range of pressures - from those typical for a laboratory explosion experiment to values tens to hundreds of times exceeding its capabilities. As an example of the results obtained in the described experiments, we can cite dependencies illustrating the above-mentioned phenomenon of loss of individuality of substances at high pressures. Fig. 4 shows the change in the atomic volumes of some metals depending on pressure. Under normal conditions (P = 0, T = T0), there is a well-defined periodic dependence of the atomic volumes (Vaт) of elements on the atomic number Z, which corresponds to successive fillings of the energy levels of atoms with electrons. The periodicity of this dependence is determined by the difference in the behavior of loose structures (alkaline and alkaline earth elements with weakly bound electrons of s-levels) and close-packed structures with a large number of electrons filling d-levels (transition metals). With increasing pressure, the atomic volumes of the elements equalize. In this case, the greatest changes occur in elements with a loose structure. At a pressure of 300 GPa, the periodicity of Vat(Z ) is already weakly manifested, and at P > 1000 GPa (underground nuclear explosions) it practically disappears.

Study of the process of destruction of materials during rapid volumetric heating by penetrating radiation of a nuclear explosion

Depending on the radiation spectrum, material and thickness of the irradiated barrier, exposure to nuclear weapons radiation may result in either intense heating (and even evaporation) of the thin surface layer of the barrier, or its volumetric heating.

In the first case, the dispersion of the evaporated surface layer leads to the formation of a compression shock wave propagating inside the barrier, in the second case, two compression and expansion waves arise in it, the amplitude of which in the region of existence of the solid phase is proportional to the concentration of the absorbed energy. The interaction of two counter-propagating waves of the latter type creates tensile stresses in the material, leading to the destruction of the barrier (destruction during the interaction of waves is called spallation). Destruction of this type can also be caused by the action of radiation from other physical installations (linear electron accelerator), by the impact of a high-speed striker in the form of a flat plate and by the explosion of a layer of explosives in contact with the studied sample. The use of pulsed radiation sources for loading allows us to penetrate into the region of record-breaking short time intervals of load action (up to 10-10 s), which provides unique opportunities for studying the physical nature of dynamic destruction of materials, the knowledge of which is of great importance for predicting the operation of installations operating at a high energy input rate (pulse accelerators, reactors, etc.).

The conducted studies allowed us to reveal many subtle details of the process of pulsed destruction of heated materials. For example, Fig. 5 shows the time dependence for the destruction process obtained in experiments with an electron accelerator and a nuclear explosion in the coordinates lg t -E(t)/(H + L), where t is the durability of the material, E(t) is the density of the absorbed energy, L is the heat of fusion, and H is the enthalpy. The experimental points in Fig. 5 correspond to different metals. The presented dependence leads to the remarkable conclusion that for all the metals studied, the ratio of E to the value of H + L for the same durability values practically coincides and is a constant [3].

EXPLOSIVE NUCLEAR POWER

Mankind is currently going through a very difficult period: fossil fuel reserves are running out, the population is growing sharply_ There is no point in seriously counting on alternative energy sources (solar, geothermal, etc.). They are characterized by low energy density, and the costs of concentrating it are too high. In essence, hopes for uranium energy are not justified. The isotope 235U makes up only 0.7% of the 2.6 million tons of natural uranium reserves. The energy content of this amount of 235U is an order of magnitude less than the proven reserves of oil and gas. The energy reserves of 238U are an order of magnitude greater than those of oil and gas, but 238U must first be converted into plutonium:

The rate of such conversion in conventional stationary breeder reactors does not exceed 1% per year of the stored 238U, that is, the energy release is too slow.

But the possibilities of nuclear energy are not exhausted. In addition to the fissile materials that modern nuclear power plants use, there are practically unlimited reserves of deuterium on Earth. It can be used in thermonuclear fusion reactions with the release of enormous energy. Research is being conducted all over the world to master controlled thermonuclear fusion (CTF). But the practical use of CTF is apparently still a long way off. The fusion reaction requires a temperature and density greater than on the Sun. Under terrestrial conditions, due to the small volume of fuel, an even higher temperature and density are required, which can only be realized in a nuclear explosion. The authors of [2] believe that deuterium energy can only be explosive. Today, only relatively powerful deuterium explosions of the kiloton scale can be considered controlled. The first publications and proposals on possible tests of nuclear explosions for energy purposes appeared almost simultaneously with the first tests of nuclear charges. Publications by Russian scientists on the issues of energy application of nuclear weapons are practically unknown. In 1977, A.D. Sakharov published an article in New York, "Nuclear Energy and the Freedom of the West," in which he referred to some research conducted at VNIIEF (Sarov). The essence of the proposal was "the use of thermonuclear explosions of the lowest possible power_ in a large underground chamber to produce plutonium, which would then be burned in nuclear reactors."

In the early 1960s, VNIIEF began experimental and design work aimed at creating devices for holding nuclear explosion energy. The author of this article had the opportunity to participate in experimental studies on the development of closed steel chambers designed to solve this problem. The project was not completed, but it allowed obtaining unique experimental material on the possibility of carrying out sufficiently powerful multiple explosions in closed chambers.

In recent years, renowned scientists from VNIITF (Snezhinsk) have proposed a project to create a new installation for converting nuclear energy, which they called an explosive combustion boiler (ECB). The proposed concept assumes obtaining the main share of energy due to explosions of deuterium, the reserves of which are practically unlimited. To ignite deuterium, an initiator made of plutonium is used, which is produced in reaction (1) due to neutrons formed during deuterium combustion. Such neutrons are formed two orders of magnitude more than the plutonium nuclei burned in the initiator, so obtaining fissile materials in quantities significantly exceeding one's own needs will not be difficult.

One of the main elements of the KVS is a durable steel boiler, in which nuclear explosions are produced at a certain frequency. The thermal power of such a boiler will be W = Q / t (Q is the energy release of one nuclear explosion, t is the frequency of explosions). The hot coolant (sodium, T © 550?C) is contained in the lower part of the chamber (a durable steel cylinder with a diameter of 130 m and a height of 250 m). In an hour, ~ 200 thousand tons of coolant are pumped through the heat exchanger, cooled to ~ 120?C and fed to the storage tanks. The working fluid of the turbine is heated in the heat exchangers, rotates the turbines, cools and is fed back to the heat exchanger.

The chamber volume is filled with inert gas. A few minutes before the explosion, the nuclear charge is introduced into it, a few seconds before the explosion, sodium is released from the storage tanks and flies down, forming a protective layer between the nuclear charge and the chamber body. After the explosion, most of the energy is transferred to the gas in the form of ionization energy, thermal motion and kinetic energy of the gas mass. The latter part determines the mechanical impulse, the impact of which the steel chamber must withstand. The authors believe that it is realistic to design a KVS with a steel mass of less than 1 million tons, in which explosions with an energy release of 25 kt e.e. can be carried out with a frequency of 1 hour. The capacity of such an installation will be 25 GW.

The cited book [2] ends with the words: "Explosive deuterium energy is possible_ It is ecologically safe and economical. Russia has scientific and technical potential capable of convincing the world of this, working in old jobs_ This can be done in the first five-year plan of the 21st century, if we start today."

The material presented was intended to demonstrate the enormous potential of nuclear explosions in the interests of science and industry. And although many projects today still seem fantastic, one thing is clear: if nuclear explosions are tamed, made safe, truly controllable, many problems of the future can be successfully solved.

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